

MEASUREMENT OF PERSISTENT ORGANIC POLLUTANTS (POPS) IN ENVIRONMENTAL SAMPLES

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PCDFs, PCODs, PCBs, HCB, DDT, Chlordane, Heptachlor, Dieldrin, Mirex, Toxaphene, Aldrin, Endrin



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Persistent Organic Pollutants (POPs) in Indian Aquatic Environment

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1. Introduction

Extensive production and usage of anthropogenic chemicals has resulted in damage of environment and habitat. However, pertaining to the safety of the environment, the chemicals damaging the environment are being banned for use by all nations globally. The chemicals identified and categorised under persistent organic pollutants (POPs) are resilient to environmental degradation by means of chemical, biological, or photolytic processes. Therefore, POPs continue to exist in the environment for a prolonged time with ability for long-range atmospheric transport, bioaccumulation and biomagnification.

As of now, Stockholm Convention (2014) has listed 22 chemicals as POPs which includes Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene (HCB), Mirex, Toxaphene, Polychlorinated biphenyls (PCB), Polychlorinated dibenzo-p-dioxins (PCDD), Polychlorinated dibenzofurans (PCDF), α -Hexachlorocyclohexane, β -Hexachlorocyclohexane, Lindane, Chlordecone, Hexabromobiphenyl, Hexabromodiphenyl ether and Heptabromodiphenyl ether, Pentachlorobenzene, Perfluorooctane sulfonic acid (its salts) and Perfluorooctane sulfonyl fluoride, Endosulfan and isomers, and Tetrabromodiphenyl and pentabromodiphenyl ethers in the banned or to be eliminated category.

The usage of POPs varies with respect to country and it is well identified as shown in pesticides (Fig. 1). India being the largest producer of pesticides next to China in

Asia, and ranks 12th in the world for application of pesticides (Bhardwaj and Sharma, 2013). The present registered pesticides are about 150, including few of the banned items. As an advent of green revolution, huge amount of pesticides were produced during 1998 (102,240 tonnes) (Kumar *et al.*, 2013b) and the usage was reduced during 2013 to 50,583 tonnes (SCCF, 2013). Although organochlorine pesticides (OCPs) formed the majority of the usage (70%) in olden days, shift in usage of organophosphate (methyl parathion, malathion and ethion) pesticides and synthetic pyrethroids is recently witnessed (Agrawal *et al.*, 2010). Due to lack of alternatives, some of the banned pesticides such as DDT and lindane are legally in use for vector control in many developing countries including India. Other than pesticides, the PCBs stock in India was assessed as up to 28000 MT and the total emission of dioxins estimated as ~8.6 Kg toxic equivalent (TEQ) (Sharma, 2013).

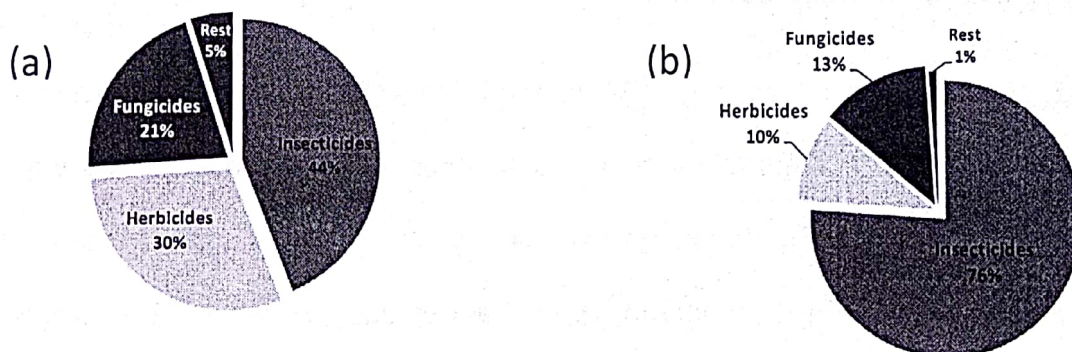


Fig.1 Pesticide usage scenario at global (a) and Indian (b) level (Mathur, 1999)

About 100,000 chemicals have entered into the market since 1945, and it is estimated that 75,000 of them are in commercial use. As of now, only about 3% (about 1200) of these chemicals have been tested for carcinogenicity (Sanghi,

residues were reported in water and sediment up to 567 ng/l and 813 ng/g, respectively.

In case of Yamuna river (another major tributary of the River Ganga) flowing through New Delhi with a catchment area of 1485 sq.km, water samples showed Σ HCH, Σ DDT and Σ OCPs in the range of <0.1 - 285, <0.1 - 354 and <0.1 - 618 ng/l, respectively with highest contribution from HCHs (62%) and DDTs (38%) (Kumar *et al.*, 2012). Additionally, ratio between DDTs (p,p'-DDT/p,p'-DDE of 2.51) indicated recent input (Kumar *et al.*, 2012). Pandey *et al.* (2011) witnessed significant prevalence of endosulfan sulfate, DDT, Endrin aldehyde, DDD and Methoxychlor in all the seasons in sediment from Yamuna river. A recent study on fluvial sediments from the Yamuna River revealed high levels of Σ_{20} OCPs (21.4 to 139 ng/g) of which Σ HCH and Σ DDT constituted ~ 86 %. β -isomer was observed as the most predominant component of HCH, while analysis of isomer ratio indicated fresh usage of technical-grade HCH, lindane and DDT (Parween *et al.*, 2014).

Another major river, Ghaggar, flowing from Himalayas through districts of Punjab, Haryana and Rajasthan was sampled at 12 sites in Haryana (230 km stretch) and the predominant OCPs in water were DDT (238 - 1005 ng/l) with 72.85 % of p,p'-DDT and HCH (21 - 244 ng/l) with 96.6 % of β -HCH, whereas, aldrin and dieldrin were below detection limit. Further, it is obvious that the concentration of Σ DDT > USEPA (1995) standard for freshwater aquatic life (1.0 ng/l) and EC directive (1998) for drinking (100 ng/l) (Kaushik *et al.*, 2010).

In Sharda River (2009 - 2010) at Lakhimpur Kheri in Uttar Pradesh, DDTs and HCHs were measured up to 236 ng/l and 277 ng/l, respectively. Other than these pesticides, heptachlor oxide (35 ng/l) and dieldrin (29 ng/l) were detected at one location (during 2009) among the investigated 21 OCPs (Maurya and Kumar,

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2013). Even water bodies (rivers and streams) in Northeast (Dibrugarh and Nagaon districts) Assam showed higher HCHs (4911 ng/l) and DDTs (6121 ng/l). Shockingly, HCH and DDT in 90 % samples exceeded the WHO recommended drinking water limits (2000 ng/l and 1000 ng/l, respectively) and also expected to pose a serious threat to aquatic ecosystem (Mishra and Sharma, 2011).

Study on POPs in sediments along the lower stretch of Hugli estuary, West Bengal showed decreased concentration of HCH, HCB and DDT as 0.11 - 0.4, <0.05 - 0.98 and 0.18 - 1.93 ng/g dry weight (dw), respectively (Guzzella *et al.*, 2005). In case of sediment cores from Sunderban wetland, showed relative level of Σ HCHs, HCB, and Σ DDTs in the range of 0.05 - 12, 0.05-1.4, and 0.05-11.5 ng/g dw, respectively (Sarkar *et al.*, 2008) with Hugli estuary. A recent study on depth profile of accumulated OCPs in sediments (by ^{210}PO activity) of Thane Creek, Mumbai reported that contamination of DDT and HCH were high during 1970-80 (i.e. just after the green revolution in India). Further the study reported lower levels of HCH (5.6 -13.3 ng/g) and DDT (3.2-5.5 ng/g) in surface sediment samples (Pandit *et al.*, 2014), than most of the rivers in northern/north-eastern India.

Limited studies are available in recent past about the pesticides in southern India. The OCPs in southern Indian river, Tamiraparani, was estimated by us (Kumarasamy *et al.*, 2012) and levels of Σ_{17} OCPs in surface water and sediment were in the range of 0.1 to 80 ng/l and 0.12 to 3938 ng/g dw, respectively. The level of DDTs, aldrin, dieldrin, chlordanes and mirex were dominant in sediment whereas in water samples it was heptachlor, o,p'-DDE, dieldrin, o,p'-DDD, and mirex. Further, mirex (banned termiticide) an unregistered pesticide observed, may be due to its usage in plastics and consumer goods as flame-retardants. Another survey on Σ_{19} OCPs in open water and sediments of agricultural areas of Kanyakumari

district, Tamil Nadu showed concentration in the range of 5.68–25.12 ng/l and 17.7–58.59 ng/g dw respectively with dominant OCPs as HCHs, DDTs and heptachlor epoxide (Jeyakumar *et al.*, 2014).

Apart from OCPs, the detection of OPPs signifies the shift in usage of pesticides. However, degradable OPPs level in aquatic environment may perhaps affect the ecosystem. A survey in Kanpur, northern India, has shown the presence of high concentrations of organophosphorous pesticides in Ganga river water (malathion up to 2618 ng/l) (Sankararamakrishnan *et al.*, 2005).

1.2 Ground water

Fewer studies are available for pesticides in ground water. However, pesticides seem to contaminate groundwater invariably in most of the aquifers in India. The total pesticide levels were as high as 1058 µg/l in Jaipur (Northern India) (Bakore *et al.*, 2004) and in southern India (Tamilnadu and Kerala), it was 12.4 – 61.13 µg/l (NGRI Proceedings, 2013). Dieldrin (29836 ng/l) and OPPs are also highly reported in Kanpur (both agriculture and industrial locations) which are well above the EC and BIS limits (1000 ng/l) (Sankararamakrishnan *et al.*, 2005). DDT and HCH levels in groundwater from Dibrugarh and Nagaon districts in Assam were 6549 ng/l and 6904 ng/l, and 5168 ng/l and 5574 ng/l, respectively (Mishra and Sharma, 2011). Even, aquifer in Godavari plain of Nanded district, Maharashtra showed ubiquitous contamination of HCB and DDT at levels beyond the permissible limits of European drinking water standard (1000 ng/l and 2000 ng/l, respectively), and the reported concentration of aldrin/dieldrin, endosulfan, heptachlor, HCB and DDT were in the range of 10 - 40, 1500 - 4000, 10 - 30, 1000 - 2000 and 2000 - 4000 ng/l, respectively (Motekar, 2011).

1.3 Coastal Sediment

Marine sediment samples collected along the coast of Bay of Bengal, Tamilnadu showed concentration of Σ DDTs and Σ HCHs in the range of 0.04–4.79 and 0.17–1.56 ng/g dw (Rajendran *et al.*, 2005). In Cochin estuary of Kerala, higher levels of Σ DDTs and Σ HCHs in sediments were reported in the range of 229–418 and 23.7–423 ng/g dw, respectively (Akhil and Sujatha, 2014) which are higher than most of the Indian rivers.

Further, based on available reports, Sharma *et al.* (2014) analyzed the distribution pattern of POPs in multi-compartment environment at time scale (23 years) and found a declining trend of HCHs in surface waters as directly reflecting the ban on technical HCH production and use from 1997 (Fig. 2).

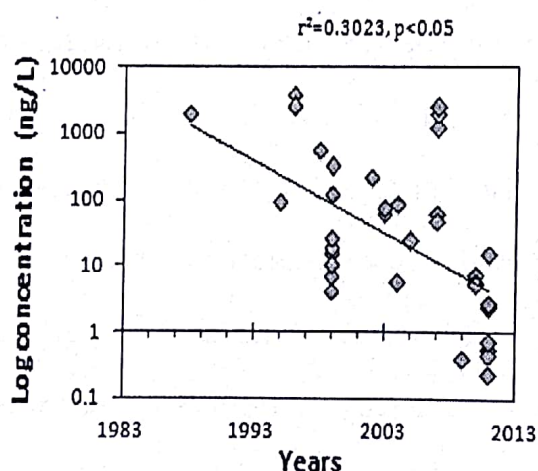


Fig. 2 Declining trend of HCH in surface waters of India (Sharma *et al.*, 2014)

1.4 Biota

OCPs are persistent, non-target specific, lipophilic, and being bioaccumulative they biomagnify in food chains. They can show toxicity directly by inducing cellular toxicity or indirectly at low concentration through endocrine disruption in organisms.

OCPs were analysed in Irrawaddy dolphins from Chilika Lake (Odisha) upto 10,000 and 1200 ng/g lipid wt of DDT and HCH, respectively (Kannan *et al.*, 2005). Fishes collected from Gomti River showed OCPs from 2.58 to 22.56 ng/g with aldrin as a predominant one (Malik *et al.*, 2007). Concentration of HCHs and DDTs in fish samples from Veeranam Lake (Tamilnadu) was reported to be 0.82 - 3.5 and 0.03 - 3.3 ng/g ww, respectively (Bhuvaneshwari and Rajendran, 2012). Elevated concentrations of OCPs in marine (10.47 ng/g ww), brackish (70.57 ng/g ww) and freshwater (28.35 ng/g ww) fishes were reported from Calicut, Kerala. Among OCPs, BHC and heptachlor epoxide contributed more in marine fishes, whereas BHC contributed more in other fishes (Sankar *et al.*, 2006).

2. Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are collection of more than 100 different chemicals formed during incomplete combustion of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat. Among the PAHs, benz(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, and indeno(1,2,3-c,d)pyrene are known animal carcinogens (ATSDR, 1995).

PAHs were extensively studied in core sediments of Sundarban mangrove wetland in Ganga delta region (Dominguez *et al.*, 2010; Sarkar *et al.*, 2012; Zuloaga *et al.*, 2013) and found to increase over years. Domínguez *et al.* (2010) reported $\Sigma 16$ PAHs in the range of 132 - 2938 ng/g dw. Following the above study, Sarkar *et al.* (2012) and Zuloaga *et al.* (2013) recorded $\Sigma 19$ PAHs up to 4222 ng/g dw and 12993 ng/g dw, respectively. Further, Zuloaga *et al.* (2013) observed Fluoranthene (up to 1,839 ng/g dw), pyrene (1572 ng/g), benzo(b)fluoranthene (1124 ng/g) and dibenzo (a,h) anthracene (952 ng/g) as predominant species in India and Bangladesh part as well. The source for these PAHs ascertained to be of both

petrogenic and pyrolytic origin. In addition, bivalves collected from this wetland also showed PAHs in different tissues at the level of 21.4 - 5919 ng/g dw, but with higher amount of high molecular weight PAHs (Zuloaga *et al.*, 2009). In addition, acenaphthylene and fluorine in the bivalves were at levels to cause potential biological impact.

PAHs investigated in Gomti River showed the total concentrations of 16 PAHs in water and bed sediments ranged between 0.06 and 84.21 µg/l, and 5.24 and 3,722 ng/g dw, respectively (Malik *et al.*, 2011) and predominantly with 2 - 4 rings PAHs. Malik *et al.* (2008) reported accumulation of PAHs in fishes of Gomti River at 12.85 - 34.89 ng/g ww during pre- and post-monsoon seasons during 2004 - 2005. The predominant PAH was Naphthalene, whereas, high molecular weight (HMW) PAHs (benzo(k)fluoranthene, benzo(a)pyrene, indeno(123-cd)pyrene and benzo(ghi)perylene) were not detected in any of the samples. The study also inferred that LMW PAHs (2 ring constituted to 82.5 %) were found dominant irrespective of seasons. At lower stretch of Hugli estuary (West Bengal), sediment PAHs ranged from 2.5 to 1081 ng/g, predominantly by 4-ring PAHs (fluoranthene, chrysene, pyrene and benzo(a)anthracene) (Guzzella *et al.*, 2005). Nainital and Bhimtal Lakes in upper reaches of Kumaun Himalayas witnessed PAHs level ranged between 1 - 217 ng/mg C, generally increasing upwards in the core (Choudhary and Routh, 2010).

In Mumbai harbour, PAHs in water and sediment samples were observed up to 46.7 µg/l and 134134 µg/g dw, respectively (Dhananjayan *et al.*, 2012). Unlike other sediment, HMW dominated with input from pyrolytic and petrogenic sources. Fishes (5 species) collected from the Mumbai harbour showed 15 PAHs in the range of 17.43 - 70.44 ng/g ww and predominantly with LMW PAHs (eg.

naphthalene up to 34 ng/g) similar to sediment profile (Dhananjayan and Muralidharan, 2012). Further, they estimated the intake of PAHs through fish consumption for the general population up to 10.70 ng/kg body weight/day and the calculated cancer risk value (1.43×10^{-6}) slightly exceeded the USEPA guideline value (1.0×10^{-6}) for potential cancer risk. Report on mangrove and estuarine sediments from southeast India, showed an increasing trend of Σ PAH since 1970s, coinciding with rapid urbanization. As of other sediment, LMW PAHs were abundant with high contribution from petrogenic sources (Ranjan *et al.*, 2012). Further, green mussel *Perna viridis* collected from coastal locations such as Mahim, Madras, Digha, Mumbai and Kanyakumari showed PAHs in the range 67 - 1133 ng/g dw (Isobe *et al.*, 2007).

In case of ground water, urban sites at Gorakhpur, Uttarpradesh showed 16 priority PAHs with concentration ranging from 9.89 ng/l to 50.55 ng/l with mean of 23.21 ng/l. The percentage contribution of 3-ring, 4-ring and 5-ring PAHs were 41%, 19% and 19%, respectively (Masih and Lal, 2014).

3. Polychlorinated Biphenyls (PCBs)

PCBs belong to a family of synthetic organic chemicals known as chlorinated hydrocarbons. PCBs cause cancer, plus a variety of other adverse health effects on the immune system, reproductive system, nervous system and endocrine system (USEPA).

Investigation of 28 PCBs in water and sediment from Yamuna River at Delhi showed its concentrations from 2 to 779 ng/l (Kumar *et al.*, 2012) and 0.20 to 21.16 ng/g dw (Kumar *et al.*, 2013a), respectively. Mainly, tri and tetra - PCBs accounted for the major portion in water (60 %) and sediment (84 %) as well. Further, they

found dioxin-like polychlorinated biphenyls (0.04 - 2.86 ng/g dw) up to 10% of total PCBs. In case of sediment from Hugli estuary, West Bengal, the concentration of PCBs (0.18–2.33 ng/g dw) was slightly lower than Yamuna river (Guzzella *et al.*, 2005). Total PCBs in water and sediment samples from Chennai and Cuddalore fishing harbour in Tamilnadu were in the range of 0.002 - 0.004 ng/l and 0.02 - 6.57 ng/g dw, respectively (Rajendran *et al.*, 2005). In seawater, low chlorinated biphenyls (di-, tri- and tetra-) accounted for higher proportion (74.4 - 85.6 %) whereas sediment showed tetra-, penta- and hexachlorobiphenyls as major constituents (65 – 78 %).

Fish samples collected from various parts of India showed the mean PCBs concentration at 440 ng/g lipid wt (Devanathan *et al.*, 2012). PCBs in Irrawaddy dolphins (*Orcaella brevirostris*) from Chilika lake, Odisha (28 - 390 ng/g lipid wt) are much lower (10 -100 folds) than reported earlier from Ganga river and Bay of Bengal (Kannan *et al.*, 2005). Further, the PCBs burden was at least one order of magnitude lower than pesticides (DDT and HCHs). From the above reports, it is understood that trichlorinated PCBs are the dominating homolog, which coincides with its wide usage in electric power capacitors and transformers (You *et al.*, 2011).

4. Polybrominated Diphenyl Ethers (PBDEs)

Polybrominated diphenyl ethers are organobromine compounds used as flame retardants in wide array of products such as building materials, electronics, furnishings, motor vehicles, airplanes, plastics, polyurethane foams, textiles, etc. PBDEs in Indian environment are scarcely reported. In Sundarban mangrove core sediments, twelve PBDE congeners were reported at 0.08 - 29.03 ng/g dw (Binelli *et al.*, 2007) with tetrabromodiphenyl ether in all the samples and the investigation

indicated the discharge of municipal wastewater along with local industries (including textile plants) at the upstream (Hogaly river) as the prime source. The mean concentration of PBDEs and Hexabromocyclododecane in Indian fishes (n=100) was 17 and 3.0 ng/g lipid wt, respectively (Devanathan *et al.*, 2012). Likewise, PBDEs in Irrawaddy dolphins recorded in the range of 0.98 - 18 ng/g lipid wt (Kannan *et al.*, 2005) with high contribution of BDE 47 (60% - 75%) to total PBDEs. Moreover, PBDEs levels were relatively lower than PCBs and pesticides. Ramu *et al.* (2007) reported PBDEs in green mussel collected from Tamil nadu at 1.4 – 2.7 ng/g lipid wt with higher fraction of mono to hepta BDE.

5. Perfluorooctane sulfonic acid (PFOS)

Perfluorooctane sulfonic acid comes under the recently identified POPs group. Perfluorinated chemicals (PFCs) are used in consumer and industrial applications since 1960 for its resistance to thermal, chemical, and biological degradation. In addition, PFCs were preferentially used in manufacture of textiles, paper products, carpets, surfactants and lubricants, and as performance chemicals in fire-fighting foams, due to their oil-, stain-, and water- repellent features. The emissions (direct and indirect) of these high stability chemicals during the course of manufacture, use, and disposal, led to their widespread distribution in the environment (Mak *et al.*, 2009).

PFOS in River water (n=42), fish (n=28) and shrimp (n=2) samples collected from southern India and Ganga River were at ng level (Yeung *et al.*, 2009). Furthermore, water samples from Ganga River (Rishikesh) showed no PFOS, whereas the concentration gradually increased downstream with major contribution at confluence of Yamuna River in Allahabad. The flux estimate for PFOS from the

Ganga to the Bay of Bengal was 142 kg/year. In case of biota, PFOS concentrations (0.151 – 83.9 ng/g ww) increased from lower trophic level (i.e. shrimp) to higher trophic level organisms (i.e. fishes and dolphins) and showed high bioconcentration factor (BCF 5500) than other PFCs. Nevertheless, the level of the PFOS reported in India was less than the global reports (Yeung *et al.*, 2009). Another study in surficial sediments of the Ganga River and adjacent Sundarban mangrove wetland also showed very low concentration of PFOS (i.e. below the detection limit) in all 13 stations (Corsolini *et al.*, 2012).

6. Conclusion

Survey on POPs in Indian aquatic environment shows their rampant contamination throughout the country. The level of contamination varies according to the type of pollutant and its localisation. Despite the declining trend of pesticide usage, the level of pesticides, especially DDT and HCHs is exceeding the safety guideline values in some of the rivers, and in ground water. Application of DDT in malaria control programme may contribute to higher DDTs in the aquatic environment. In case of PAHs, steady increase in concentration over the years witnessed with respect to industrial expansion and upsurge in anthropogenic activities. Further, PCBs, PBDEs and PFOS residues in rivers show their ubiquitous presence in the Indian aquatic system. The presence of a wide array of these endocrine disrupting chemicals may cause a threat due to anticipated synergistic effect. Additionally, it is necessary to check the footprint of POPs through regular monitoring to stop deterioration of the environment and human health.

Table 1 Pesticides, PAHs and PCBs in Indian aquatic environment

Location	River/ Water body	Pesticides				Σ PAHs	Σ PCBs	Reference
		□DDT	□HCH	□Endosulfan	□OCP			
Water (ng/l)								
Haryana	Ghaggar	238 - 1005	21.13 - 244	BDL	NA	NA	NA	Kaushik <i>et al.</i> , (2010)
Uttar Pradesh	Gomti	NA	NA	NA	NA	60 - 84210	NA	Malik <i>et al.</i> , (2011)
Bhagalpur (Bihar)	Ganga	ND - 489	NA	BDL - 208	NA	NA	NA	Leena <i>et al.</i> , (2012)
Delhi	Yamuna	<0.1 - 354	<0.1 - 285	NA	<0.1 - 618	NA	2 - 779	Kumar <i>et al.</i> , (2012)
Tamil Nadu	Tamiraparani	<0.01 - 0.7	<0.01 - 0.78	NA	0.1 - 79.9	NA	NA	Kumarasamy <i>et al.</i> , (2012)
Uttar Pradesh	Sharda	236.5*	277.2*	ND	NA	NA	NA	Maurya and Kumar, (2013)
Indo-Gangetic plains, Unnao, Uttar Pradesh	Streams, Ponds	BDL - 230	1880 - 1950	BDL - 130	2630 - 3720	NA	NA	Singh <i>et al.</i> , (2007)
Kanyakumari (Tamil Nadu)	Tanks	1.1 - 7.1	0.8 - 6.99	NA	3.47 - 25.12	NA	NA	Jeyakumar <i>et al.</i> , (2014)
Tamil Nadu	East Coast	5.6 - 12.54	NA	NA	NA	NA	1.93 - 4.45	Rajendran <i>et al.</i> , (2005)
Mumbai (Maharashtra)	Harbour Line	NA	NA	NA	NA	<1 - 104,070	NA	Dhananjayan <i>et al.</i> , (2012)
Sediment (ng/g dw)								
Uttar Pradesh	Gomti	NA	NA	NA	NA	5.24 - 3,723	NA	Malik <i>et al.</i> , (2011)
Champanala (Uttar Pradesh)	Ganga	29.2 - 3103	NA	73.49 - 338	NA	NA	NA	Leena <i>et al.</i> , (2012)
Tamil Nadu	Tamiraparani	<0.01 - 857	<0.01 - 472	NA	0.12 - 3938	NA	NA	Kumarasamy <i>et al.</i> , (2012)
Delhi	Yamuna	40.49*	81.26*	14.12*	21.41 - 140	NA	NA	Parween <i>et al.</i> , (2014)
Delhi	Yamuna	NA	NA	NA	NA	NA	0.2 - 21.16	Kumar <i>et al.</i> , (2013a)
Kanyakumari (Tamil Nadu)	Tanks	5.2 - 18.2	5.69 - 13.59	NA	17.7 - 58.59	NA	NA	Jeyakumar <i>et al.</i> , (2014)
Tamil Nadu	East Coast	0.04 - 4.8	0.17 - 1.56	NA	NA	NA	0.019 - 6.57	Rajendran <i>et al.</i> , (2005)
Mumbai (Maharashtra)	Harbour Line	NA	NA	NA	NA	17 - 134134	NA	Dhananjayan <i>et al.</i> , (2012)
West Bengal	Hugli	0.18 - 1.72	0.11 - 0.4	NA	NA	25 - 1097	0.18 - 2.33	Guzzella <i>et al.</i> , (2005)
Sundarban Mangrove	Estuary	1.72	0.4	NA	NA	NA	NA	Binelli <i>et al.</i> , (2007)
Sundarban Mangrove	Wetland	NA	NA	NA	NA	NA	NA	(2007)
Sundarban Mangrove	Wetland	0.05 - 11.47	0.05 - 12.4	NA	NA	NA	NA	Sarkar <i>et al.</i> , (2008)
Sundarban Mangrove	Wetland	NA	NA	NA	NA	122 - 533	NA	Zuloaga <i>et al.</i> , (2009)
Sundarban Mangrove	Wetland	NA	NA	NA	NA	264 - 1421	NA	Dominguez <i>et al.</i> , (2010)

* - Maximum Value; NA - Not Available; ND - Not Detected; BDL - Below Detection Limit

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